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13. ABSTRACT (Maximum 200 words) The Space Vehicles Directorate, in collaboration with the Airborne Laser (ABL) Program Office collected data in the measurement and understanding of atmospheric optical turbulence. Optical turbulence, or fluctuations of the index of refraction in both space and time, is not only apparent in twinkling stars, but is also a major source of performance degradation for high-energy laser systems. Optical turbulence is caused by the presence of adjacent parcels of air, at a slightly different index of refraction moving about in a beam of light. In the presence of optical turbulence, a projected laser beam appears to wander, broaden and scintillate, thereby reducing image quality, and effectively reducing the average power that arrives at a spot.					
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From Twinkling Stars to Theater Missile Defense

Understanding the optical turbulence phenomenon.

AFRL's Space Vehicles Directorate, Battlespace Environment Division, Tactical Environment Support Branch, Hanscom AFB MA

The Space Vehicles Directorate, in collaboration with the Airborne Laser (ABL) Program Office collected data in the measurement and understanding of atmospheric optical turbulence. Optical turbulence, or fluctuations of the index of refraction in both space and time, is not only apparent in twinkling stars, but is also a major source of performance degradation for high-energy laser systems. Optical turbulence is caused by the presence of adjacent parcels of air, at a slightly different index of refraction moving about in a beam of light. In the presence of optical turbulence, a projected laser beam appears to wander, broaden and scintillate, thereby reducing image quality, and effectively reducing the average power that arrives at a spot.

Since turbulence can significantly affect the performance of a laser weapon system, system designers and atmospheric physicists have been working together for many years exploring the feasibility of an airborne laser weapon system. That coalition continues today as members of the ABL System Program Office work toward the realization of the first ABL, which is designed to kill theater ballistic missiles with a powerful laser beam. With advances in adaptive optics, the ABL system can compensate for moderate levels of turbulence. As the turbulence worsens, the system experiences a graceful degradation in performance, increasing the time necessary to kill a theater ballistic missile. It is, therefore, imperative to know the expected range of turbulence to specify the turbulence design criteria for the system.

Researchers at the Space Vehicles Directorate measured optical turbulence for years using a balloon-borne instrument, the Thermosonde, shown in Figure 1. The instrument detects temperature differences smaller than a hundredth of a degree across a fixed horizontal distance, typically 1m, as the balloon ascends. The measure of optical turbulence in the atmosphere, C_n^2 , is computed using a running average of the temperature fluctuations along with the local temperature and pressure sensed by meteorological instruments attached to the Thermosonde.

In the summer of 1984, Army and Air Force researchers worked to characterize the optical turbulence at the White Sands Missile Range in southern New Mexico. With homogeneous weather conditions, only a moderate number of balloon ascents were required to obtain a robust average C_n^2 profile. A segmented curve fit through that average was designated the "CLEAR 1" model. An actual C_n^2 profile is plotted with the smooth CLEAR 1 model on the right side of Figure 1. The actual profile shows the layered nature of the turbulence.

Since CLEAR 1 provides a reasonably typical average C_n^2 profile from the ground up to 30km, it has become a convenient baseline for expressing the optical turbulence design criteria for optical systems. The CLEAR 1 model is a smooth function that can be easily integrated to compute optical effects such as scintillation and beam spreading. For a given scenario, the optical effect of an actual C_n^2 profile can be compared to the effect that is produced using the CLEAR 1 profile. In 1993, AFRL scientists worked with their counterparts at MIT Lincoln

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Laboratory to determine the turbulence design criteria for the ABL. Using candidate ABL engagement geometries and the existing Thermosonde database, the effect each of the turbulence profiles would have on the ABL system was computed. Assuming those 65 profiles were representative of the expected turbulence, the distribution of expected ABL performance was also computed. The optical turbulence associated with the desired level of performance was then expressed as a multiple of the performance computed using the CLEAR 1 model.

In 1996, the Air Force and the Department of Defense initiated the ABL Preliminary Design and Risk Reduction program. The first important milestone was Authority to Proceed -1 (ATP-1). One ATP-1 requirement was to confirm the global validity of the turbulence design criteria, since the 65 C_n^2 profiles available in 1993 came from the Continental United States, Hawaii, and the Azores. ATP-1 required that conditions be measured in theaters where the ABL might be used in all four seasons. The ABL Program Office and AFRL decided that scientists from the Space Vehicles Directorate would launch balloons to measure the turbulence in Northeast Asia and Southwest Asia for each of the four seasons during a two year period. In addition, scientists and engineers from the Directed Energy Directorate would measure airborne turbulence for the four seasons of one year.

In total, eleven Thermosonde missions were performed in FY97 and FY98 in NE Asia. The team also measured turbulence over two locations in SW Asia. Typically, 25 balloons were launched at each location for each season. In the end, the balloon and aircraft measurements verified the proposed ABL design for application of the weapon system in theaters of interest. With the successful completion of all requirements, the ABL program was given authority to proceed with the assembly of the first ABL aircraft.

Coincident with the start of the ATP-1 data collection, the Air Force Office of Scientific Research initiated a program to improve the understanding of the fundamental physics of the optical turbulence problem. The goal was to develop the capability to forecast optical turbulence levels and to optimize the deployment of the ABL in the theater. The program included analytical and experimental efforts. The experimental elements included the use of modified Thermosonde instruments sensing fine scale temperature fluctuations and sending data at kHz frequencies. The laboratory has participated in joint turbulence sampling programs with high-resolution radars and high altitude research aircraft at various locations around the world.

Basic research efforts to improve understanding of the basic phenomena will help to improve optical turbulence forecasts. These efforts have been greatly improved by the wealth of new Thermosonde data available. The next generation of turbulence models will be improved correlations to atmospheric and orographic conditions using the ATP-1 data. A notional view of an optical turbulence decision aid, shown in Figure 2, was assembled using an early turbulence model. The large red turbulence area at the top is associated with a jet stream positioned over the New Mexico - Colorado border. Smaller turbulence regions are also visible, the result of the strong convective activity near some of the white clouds.

Data provided by this study confirms the ABL design point is correct. Future optical turbulence data products will provide important support for planning ABL missions in the field.

Dr. George Y. Jumper and Dr. Robert R. Beland of the Air Force Research Laboratory's Space Vehicles Directorate wrote this article. For more information contact TECH CONNECT at 1-800-203-6451 or visit the web site at <http://www.afrl.af.mil/techconn/index.htm>. Reference document VS-00-04.

Figure 1. Left, the Thermosonde instrument, towed aloft by a large weather balloon. The boom supports two very sensitive temperature probes 1 m apart. Right, example Thermosonde output shown with the smooth CLEAR 1 model.

Figure 2. Notional view of a pre-mission decision aid showing clouds in white and optical turbulence in red over the southwestern United States

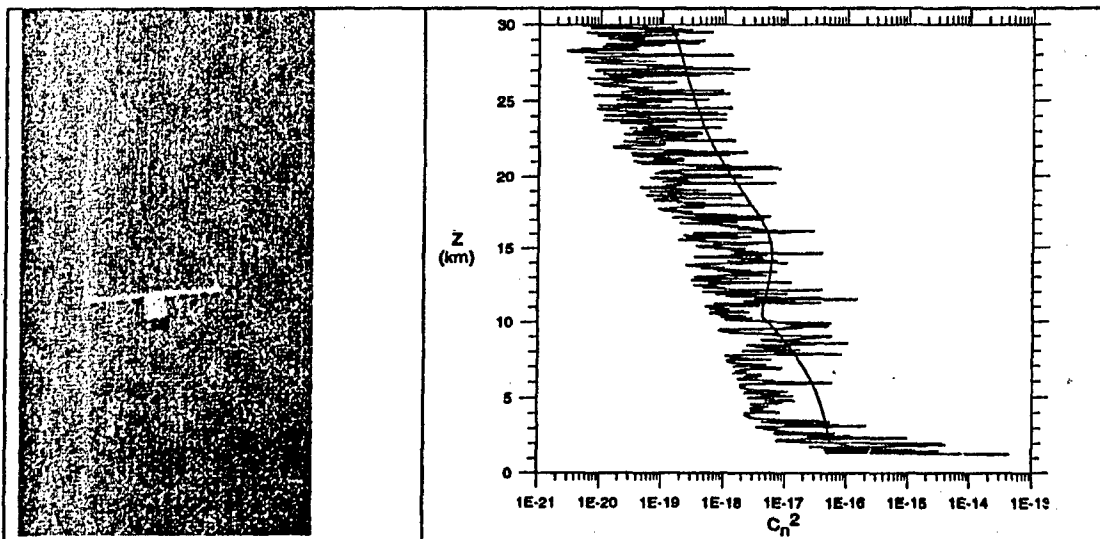


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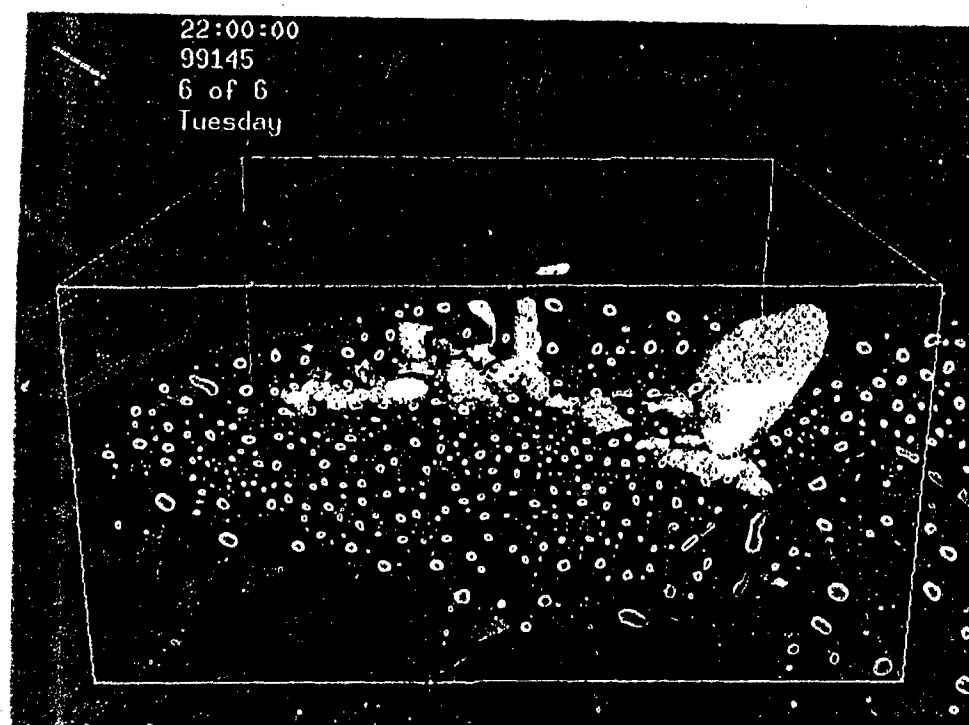


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